Comparing The Temporal Evolution of NIR and Fermi/LAT Observations of Blazars

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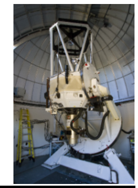


Instruments

WIRO/Goddard Infrared Camera: An infrared camera designed and build by NASA's Goddard Space Flight Center is hosted by the University of Wyoming's InfraRed Observatory's (WIRO) 2.3-m Cassegrain telescope, located on the summit of Jelm Mt. (9656 ft.). The observatory has a number of advantages, including a relatively dry climate, low air turbulence, dark sky, and strong pre-existing infrastructure. The camera holds a 256x256 InSb array, has a 100"x100" field of view, and spans *JHK*-bands.

PAIRITEL: Located on Mt. Hopkins, outside Tucson, AZ, the Peters Automated Infrared Imaging Telescope (PAIRITEL) is a fully roboticized 1.3-m telescope that allows for autonomous queue-scheduled observing. PAIRITEL utilizes the retired 2MASS instrument to obtain simultaneous infrared observations in *JHK*-bands.

Fermi/LAT: Fermi's Large Area Telescope (LAT) is its principal scientific instrument. This high-energy gamma-ray telescope is capable of observations spanning 20 MeV to more than 300 GeV.

Data

Ideally, infrared observations were to be scheduled to occur simultaneously with the Fermi campaign. Realistically, scheduling was difficult, so infrared observations were merely obtained as often as possible. The WIRO campaign has been ongoing since early in 2009, but at a cadence of only 1 week per month. The PAIRITEL campaign started in mid-2010, at a much higher cadence. Data were reduced using standard infrared reduction techniques. Typical photometric errors are about <5%.

Gamma-ray observations were obtained by the Fermi monitoring campaign. All high-energy fluxes were downloaded from the Fermi website: ***fermi.gsfc.nasa.gov/ssc/data/access/lat/msl_lc/*** Most of these fluxes are upper limits, which is a result of a non-optimized auto-processing routine that extracts the fluxes. While the auto-processed fluxes are used in most of this poster, further analysis with optimized parameters is likely necessary for future analysis. Already, Figure 2 shows the results of such optimized techniques for BL Lac 0.1-300 GeV data (Marscher, pers. Comm.), which remove the upper limits.

Motivation

Blazars are commonly considered to be AGN with relativistic jets pointed nearly directly at the observer, making them extremely bright sources (see Figure 1). The jet emits across all wavelengths spanning radio to TeV energies. This emission often varies on time scales of days, hours, and even minutes at both parsec- and subparsec distances. The source of the photons and variability remains a critical question. In some models (leptonic), the high-energy emission is attributed to synchrotron radiation from high-energy electrons and the lower-energy emission is attributed to inverse Compton scattering off of these same electrons. Alternatively, other models (hadronic) suggest the relativistic protons in the jet emit gamma-ray radiation by means of photo-pair and photo-pion production. Multi-wavelength studies, which probe different regions of an AGN, are therefore critical to understanding the physical processes responsible for the emission and variability.

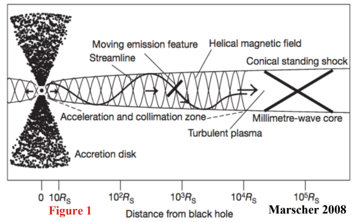
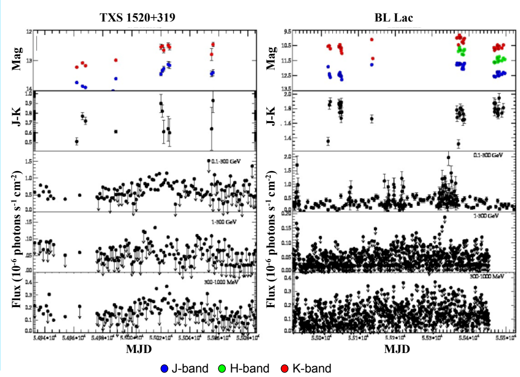


Figure 1

Marscher 2008

The panels in Figure 2 plot the preliminary results on daily timescales for targets with the largest number of infrared observations. Near-infrared data are shown in the top plots. At earlier epochs, both J- and K-band (blue and red, respectively) were obtained manually at WIRO. Observing runs typically spanned one week each month in late 2009 and early 2010. At later epochs, simultaneous JHK (blue, green, and red, respectively) observations were robotically made on a consistent basis with PAIRITEL. The second plot of each panel shows the J-K color evolution. For comparison, the observed Fermi/LAT fluxes in different energy bands are displayed in the bottom three plots of each panel.



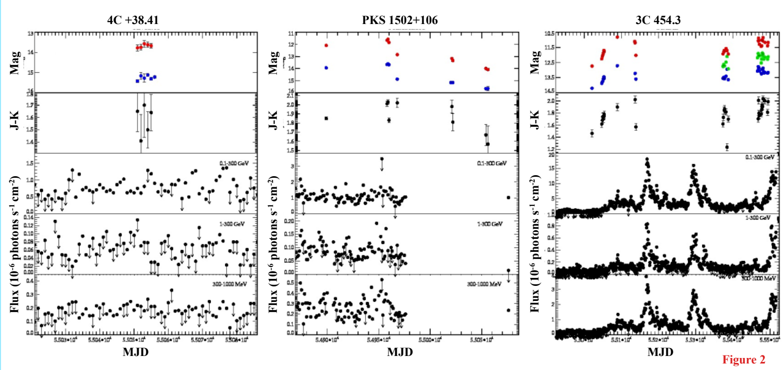


Figure 2

Target Selection

Table 1 lists the targets, which were chosen to correspond with the Fermi monitored source list of bright Blazars. Given the community-wide interest in blazar variability, Fermi/LAT provides daily and weekly averaged fluxes for a number of bright blazars.

The blazar list consists of both strong emission line Flat Spectrum Radio Quasars (FSRQ) and weak lined BL Lac type quasars. The relationship between these two types remains of great interest. One theory suggests the connection is purely an orientation effect, while others insist intrinsic differences must exist. As outlined in Sambruna et al. (1996), there may be some further connection to the bolometric luminosity and/or redshift.

Understanding the connection between these two classes is expected to advance the understanding of the fundamental nature of blazars. To this end, we have selected targets from both groups over a range in redshift, and are looking for any evolutionary effects that may exist. Given our observations are limited to the infrared, we are only looking for correlated behavior with the Fermi observations, as opposed to characterizing the spectral energy distributions.

Table 1

Blazar	Z	Type
Mrk 421	0.03	BL Lac
Mrk 501	0.033	BL Lac
1ES 1959+650	0.047	BL Lac
BL Lacertae	0.069	BL Lac
W Com	0.102	BL Lac
B2 1215+30	0.13	BL Lac
OJ 287	0.306	BL Lac
OT 081	0.322	BL Lac
OT 355	0.97	BL Lac
RXS J1543+613	-----	BL Lac
PKS 0048-097	-----	BL Lac
3C 273	0.158	FSRQ
OX 169	0.213	FSRQ
GB6 1700+6830	0.301	FSRQ
PKS 1510-089	0.36	FSRQ
3C 279	0.536	FSRQ
PMN J0948+0022	0.585	FSRQ
TXS 1846+322	0.798	FSRQ
3C 454.3	0.859	FSRQ
DA 55	0.859	FSRQ
CTA 102	1.037	FSRQ
PKS 2201+171	1.076	FSRQ
PKS 2144+092	1.113	FSRQ
TXS 1520+319	1.487	FSRQ
4C +38.41	1.814	FSRQ
PKS 1502+106	1.839	FSRQ
PKS 0528+134	2.07	FSRQ

Discussion

We look for a correlation between the infrared and gamma-ray data using IDL's CORRELATE function. We analyze only epochs that have both infrared and high-energy data available. Given the large number of upper limits and unmatched epochs, the number of data points is limited for each target. Table 2 below lists the correlation coefficients calculated for the infrared data versus the three different Fermi energy bands on daily time scales. (The negative values are due to the inverse relationship between flux and magnitude.) Table 3 lists the correlation coefficients calculated on week long time scales (when available). Overall, little correlation exists from day to day. For cases where weekly correlations were calculated (BL Lac, 3C 454.3, and TXS 1520+319) we find a general correspondence between high gamma-ray and infrared states.

For 3C 454.3 and PKS 1502+106, the color tends to become redder with brightness (see Figure 3). These results are similar to those reported by Bonning (2009) in the case of 3C 454.3. In that paper, Bonning concludes this trend suggests the presence of thermal emission beneath a much brighter non-thermal jet. The corresponding infrared and gamma-ray peaks are consistent with a model in which the jet produces infrared and optical emission from synchrotron radiation and X- and gamma-ray emission from inverse Compton radiation. The other 3 AGN tend to become bluer with brightness. The meaning of this relationship is unknown.

Table 2 - Daily Correlations

Blazar	J-Band 0.1-300 GeV	K-Band 0.1-300 GeV	J-Band 1-300 GeV	K-Band 1-300 GeV	J-Band 300-1000 MeV	K-Band 300-1000 MeV
BLLAC	-0.2	-0.295	-0.06	-0.02	-0.04	-0.23
3C4543	-0.58	-0.65	-0.34	-0.31	-0.58	-0.65
TXS1520319	-0.67	-0.13	0.03	0.186	-0.61	-0.014
4C3841	-0.25	-0.5	0.42	0.52	-0.42	0.11
PKS1502106	-0.91	-0.96	0.44	0.58	-0.8	-0.89

Table 3 - Weekly Correlations

Blazar	J-Band 0.1-300 GeV	K-Band 0.1-300 GeV	J-Band 1-300 GeV	K-Band 1-300 GeV	J-Band 300-1000 MeV	K-Band 300-1000 MeV
BLLAC	-0.283	-0.55	-0.539	-0.356	-0.244	-0.499
3C4543	-0.779	-0.777	-0.43	-0.4	-0.767	-0.757
TXS1520319	-0.934	-0.794	0.276	0.115	-0.621	-0.315

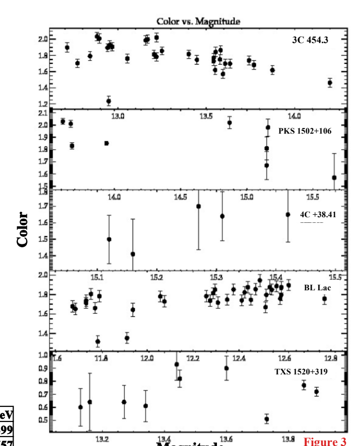


Figure 3

We stress, however, that these are preliminary results. The main purpose of this poster is to present data and observing opportunities, encourage discussion, and generate ideas. Considering the above data sets, a lack of correlation likely arises from insufficient and/or noisy data. In fact, the infrared data rarely overlaps with observed gamma ray peaks. Furthermore, IDL's CORRELATE function does not take into account any time lag or associated error bars. In the future, more complex correlation calculations will be performed, such as the discrete correlation function (DCF, Edelson & Krolic 1988; Hufnagel & Bregman 1992). Additionally, PAIRITEL's fully-automated robotic capability now provides the potential for more regular and higher cadence observations.

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